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Chapter 39: Transient Event Notification with VOEvent

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Introduction

Events and transients are becoming more and more important in modern astronomy, for example gamma-ray bursts, supernovae, microlensing, and so on. We present the VOEvent infrastructure, for communicating observations of immediate astronomical events with the intention of stimulating rapid and automated follow up from robotic telescopes. The information packet itself will be described, as well as the emerging network that allows authoring, publication, subscription, and global identifiers. VOEvent is a general, standard, flexible, peer-to-peer, robust, secure, scalable solution for this infrastructure: a vision of multiple federated event streams shared by peers and evaluated by decision support.

1. WHY we are Sending These Messages

At the forefront of modern astronomy is the time domain, the exploration of blazes and bursts, novae and supernovae, planetary eclipsing and microlensing. These, and other, phenomena require rapid follow up by multiple instruments to be fully understood.

In the next decade the scientific study of such events will be greatly extended with new survey telescopes making wide-area systematic searches for time-varying astronomical events, and with a large number of robotic facilities standing ready to respond. These events may reflect purely local solar system phenomena such as comets, solar flares, asteroids, and Kuiper Belt Objects, or those more distant such as gravitational microlensing, supernovae and Gamma-Ray Bursts (GRBs). Most exciting of all may be new and unknown types of events, heralding new horizons for astrophysics. Searches for astrophysical events are taking place at all electromagnetic wavelengths from gamma-rays to radio, as well as quests for more exotic transients detected by such means as neutrinos, gravitational waves, or high-energy cosmic rays.

For many types of events, astrophysical knowledge is gained through fast, comprehensive follow-up observation (e.g. the immediate acquisition of the spectrum of a suspected optical counterpart) and, in general, by observations made with instruments in different wavelength regimes or at different times. To satisfy these needs, several projects are commissioning robotic telescopes to respond to digital alerts by pointing the telescope and triggering observations in near real-time and without human intervention. These include, for instance, RoboNet-1.0 and eStar in the United Kingdom, and VOEventNet in the USA. Automated systems may also query archives and initiate pipelines in response to such alerts.

Many projects have been conceived, some now in operation, that will discover time-critical celestial events. These include a large number of robotic surveys and monitoring telescopes with apertures from tens of centimeters to tens of meters, large-field survey projects like Palomar-QUEST, Pan-STARRS and LSST, satellites like Swift, and more singular experiments like LIGO. RAPTOR at the Los Alamos National Laboratory is another such project that is already operating with prototype support for VOEvent.

The rate at which events are detected is expected to greatly increase as new facilities are commissioned or more fully automated, requiring that machines, not humans, handle events. Handling the anticipated event rates quickly and accurately will require *alert* packets to be issued in a structured data format, not natural language. Such a structured discovery alert, and any follow-up packets, will be referred to as a VOEvent. VOEvent will rely on XML schemata to provide the appropriate structured syntax and semantics. These schemata may be specific to VOEvent or may reference external libraries such as the IVOA's Space-Time Coordinate (STC) metadata specification or the Remote Telescope Markup Language (RTML).

Subscribing agents must be able to automatically filter a tractable number of events without missing any that may be key to achieving their goals. In general, the number of pending events from a large-scale survey telescope (such as LSST) that are above the horizon at a given observatory during a given observing session may be orders of magnitude larger than a human can sift through productively. Selection criteria will need to be quite precise to usefully throttle the incoming event stream(s). For example, a query may be something of the form: “give me all events in which a point source R-band magnitude increase of at least -2.0 was seen to occur in less than four hours, that are located within specified molecular column density contours of a prioritized list of galactic star forming regions.” In practice the result of complex queries such as these will be transmitted through intermediary *brokers* that will subscribe to VOEvent-producing systems and provide filter services to client groups (“subscribers”) via specialized VOEvents. Filtering will often be based on coincidence between multiple events, e.g. a gravitational wave detector may produce a large number of candidate events, but the interesting ones may be only those that register with multiple instruments.

VOEvent is a pragmatic effort that crosses the boundary between the Virtual Observatory and the larger astronomical community. The results of astronomical observations using real telescopes must be expressed using the IVOA VOEvent standard, be recorded and transmitted via registries and aggregators within and outside the VO, and then be captured and filtered by subscribing VO clients. Each event that survives rigorous filtering can then be passed to other real (or possibly virtual) telescopes, for instance via RTML, to acquire follow-up observations that will confirm (or deny) the original hypothesis as to the classification of the object(s) or process(es) that generated that particular VOEvent in the first place. This must happen quickly (often within seconds of the original VOEvent) and must minimize unnecessary expenditures of either real or virtual resources.

Further information can be found at `http://voevent.org` and `http://voeventnet.org`.

2. WHAT is in the Message

A VOEvent packet provides a general-purpose mechanism for representing transient astronomical events. However, not all VO data are suitable for expression using VOEvent. The VOEvent schema is simple and practical to allow the minimal representation of scientifically meaningful, time-critical, events. VOEvent also borrows other standard VO and astronomical schema, specifically STC for space-time coordinates and RTML to represent instrument configurations in addition to the usual IVOA standards such as use of the Registry and UCD identifiers. VOEvent has a strong interest in the future development of complete and robust astronomical ontologies, but must currently rely on pragmatic and immediately useful prototypes of planned facilities.

The VOEvent packet is an XML document describing what has been seen and by whom. The root element is `<VOEvent>`, and it may contain at most one of each of the following optional sub-elements:

- `<Who>` – This is the contact information (typically just the IVO identifier) for the organization that is responsible for the content of the message. The `<Who>` element can also contain a `<Date>` to specify the date and time of the creation of the VOEvent.

- `<What>` – A description of what was factually observed to occur. The `<What>` element contains a list of `<Param>` elements that may in turn be associated and labeled using `<Group>` elements in a manner similar to their use in VOTable. Each `<Param>` represents a keyword-value pair identified by *name* and *value* attributes, and may contain additional *unit* and *ucd* attributes to clarify meaning.

- `<WhereWhen>` – Space-Time Coordinates of the event. For discoveries, it is the location of the discovery and the time should be in the past, and for prediction events, the time should be in the future. Child elements allow for the STC description of the phenomenon observed as well the location of the observer. Observations of solar (system) events and those made from spacecraft are supported.

- `<How>` – Instrument configuration for the observation. A `<How>` contains zero or more `<Reference>` elements pointing to an RTML (or other) document characterizing the instrument(s) that produced the observation.

- `<Why>` – This is for an initial scientific assessment; for example, the author can say that the event was a supernova with given probability, or that the event is associated with a named object.

- `<Citations>` – This element contains the `ivo://` identifier (i.e. the IVORN) of other VOEvents that are relevant to the same astrophysical event. A sequence of instrumental observations would each cite one of the others in the chain; follow-up reports cite the IVORN of the discovery event.

- `<Description>` – This is a natural language label that can be attached to any part of the rest of the event, describing, for example, one of the parameters (like a FITS comment), the author organization, reason for doubting part of the `<Why>` section, etc. A `<Description>` may not contain a `<Reference>` element.

- `<Reference>` – The VOEvent packet should be small and nimble, not bogged down with multi-megabyte attachments. References should be used for the URLs of images, light curves, spectra, and other attachments.

Only those elements required to convey the event being described need be present; the ordering of elements is immaterial to interpretation, but may be important for efficient processing in demanding applications. The intent of VOEvent is to describe a single astronomical transient observation per packet. Multiple observations should be expressed using multiple packets. On the other hand, complex observations may best be expressed using multiple follow-up packets or via an embedded `<Reference>` to external resources such as VOTables or RTML documents. A complete description of the VOEvent syntax and semantics can be found in to protocol document at `http://ivoa.net/Documents/latest/VOEvent.html`.

3. HOW we Send These Messages

VOEvent packets express sky transient alerts; an event author has used the services of a publisher. VOEvent users subscribe to the types of alerts pertinent to their science goals. The following roles define the interchange of VOEvent semantics:

- An *Author* is a person or organization creating scientific content suitable for representation as a sky transient alert. An author will typically register with the IVOA registry, so that the `<Who>` element of VOEvent packets will typically contain only the IVOA identifier needed to retrieve the contact information for the author organization.

- A *Publisher* receives alerts from one-or-more authors, and assigns a unique identifier to each resulting packet. Either the author or the publisher generates the actual XML syntax of the event, but the publisher is responsible for the validity of the packet relative to the VOEvent schema. Publishers will register with the IVOA registry as described below.

- A *Repository* subscribes to one or more VOEvent streams, persists packets either permanently or temporarily, and runs a service that allows clients to resolve identifiers and apply complex queries to its holdings. A given packet has one Publisher, but may be held in more than one Repository. Public repositories will register with the IVOA registry.

- A *Subscriber* is any entity that receives VOEvent packets for whatever purpose. Subscribers can find out how to get certain types of events by consulting the lists of publishers and repositories in the IVOA registry. A subscrip-

tion is a filter on the stream of events from a publisher: the subscriber is notified whenever certain criteria are met. For example, the filter may involve the curation part of the event (e.g. "all events published by the Swift spacecraft"), its location ("anything in M31"), or it may reference the detailed metadata of the event itself ("whenever the cosmic ray energy is greater than 3 TeV").

- A *Broker* or *Relay*, also sometimes known as a *Filter*, is any combination of the atomic roles of Publisher, Repository, or Subscriber that also offers arbitrary application-level functionality.

3.1. Identifiers for Messages

VOEvent benefits from the IVOA identifiers developed for the VO registry. Such an identifier is called an IVORN, that is, an International Virtual Observatory Resource Name. It is required to begin with "`ivo://`", and will stand in for a particular packet. A registered VOEvent packet is one that has a valid identifier, meaning that a registry exists that can resolve that identifier to the full VOEvent packet. VOEvent identifiers thus provide a citation mechanism, i.e. a way to express that one VOEvent packet is a follow up in some fashion of a previous packet. For these reasons, VOEvent packets will often contain VO identifiers. These take the general form `ivo://authorityID/resourceKey#local_ID`, and are references to metadata packets that may be found at a VO registry or VOEvent repository. There are several types of metadata schema that the registry can hold. For the purposes of VOEvent, the principal schemata are:

- *VOEvent*: the metadata packet for an alert resulting from the observation of a transient celestial event. This schema is defined in this document.

- *VOEvent Publisher*: the metadata packet for a publisher of VOEvents, including information about who is running it, what kinds of events are published, and information about how to subscribe to the feed of published events.

- *VOEvent Repository*: the metadata packet to describe a repository of VOEvents, including the list of publishers whose events are kept, the service endpoint to query the repository, and the endpoint to resolve a VOEvent identifier.

- *Author Organization*: this metadata describes an author, including contact information and a description of the project. The VOEvent `<Who>` element contains either a reference to an author's IVORN or explicit contact information sufficient to describe the author.

When such an identifier is resolved, it means that the VOEvent metadata packet is obtained in exchange for the identifier. Such resolution happens through the global, distributed IVOA registry in stages. The registry is queried to locate a repository

holding the relevant packet, and then the repository is queried for the packet itself. The part of the IVORN before the "#" symbol points to the publisher of the event; the whole IVORN (that includes the local_ID) points to the event. Thus VOEvent identifiers are overloaded; they contain a publisher identifier, then the "#" sign, then the local reference.

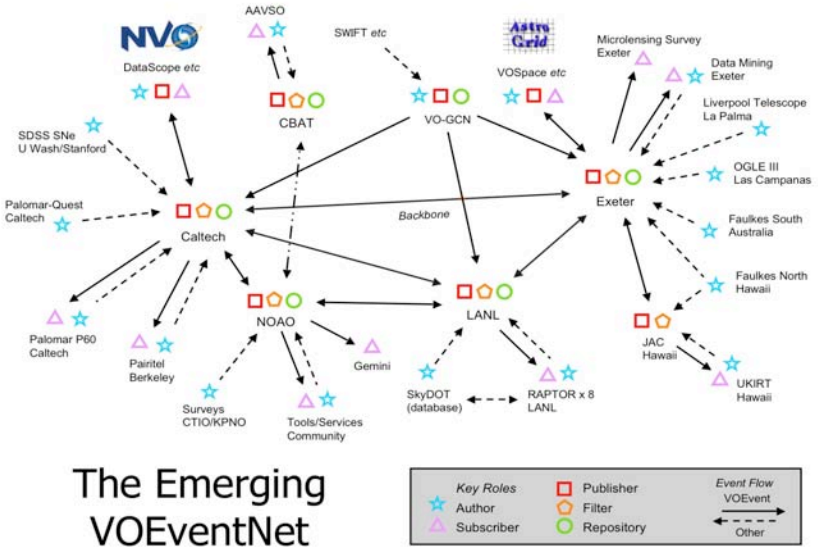

Figure 1. The VOEventNet backbone between Caltech, Exeter and Los Alamos was commissioned in July 2005. As we go to press, extensions to NOAO and VO-GCN are being commissioned. VOEventNet in the future will reach out to traditional transient alert publishers such as the Central Bureau of Astronomical Telegrams.

4. How to GET These Messages

As of June 2007 the VOEventNet project (`http://voeventnet.org, see also Figure 1`) is delivering streams of events from the following sources. Each may reference other material, and have its own collection of keywords for the `<What>` section:

- the OGLE Microlensing Search
- the SDSS Supernova Search
- the GCN-VOEvent translation, with gamma-ray bursts from NASA SWIFT etc.
- the Palomar-Quest survey

An "event" in this context means at least a VOEvent packet, and possibly references. The OGLE events for example contain references to a finding chart, a photometric data file, and a rich summary web page for human consumption. The VOEvent packet contains machine-readable parameters, for example:

```
<Param value="BLG102.4" ucd="meta.dataset" name="Field"/>
<Param value="187425" ucd="meta.id" name="StarNo"/>
<Group>
<Param units="HJD" value="2454030.115" ucd="time.epoch" name="Tmax"/>
<Param units="days" value="0.512" ucd="time.interval" name="Error"/>
</Group>
<Group>
<Param units="days" value="14.349" ucd="time.scale" name="Tau"/>
<Param units="days" value="0.906" ucd="time.interval" name="Error"/>
</Group>
```

In addition to the "Field" and "StarNo" parameters there are Group elements, which in these cases bind a value to its error: we have "Tmax", the Julian date of the time of maximum brightness, and a time interval called "Tau" at 14±1 days.

The SDSS Supernova search also has a reference to a very complete web page for each event, and it exposes for machine reading (i.e. inside the VOEvent packet itself) the light-curve of the supernova, expressed as a set of measurements, each with filter name, time, magnitude, error, and sky position.

The GCN packets expose a large number of parameters that are specific to each instrument of each satellite, and they do not reference any kind of web repository.

4.1. Client Software for Immediate Notification

The objective of the VOEvent system is to allow automated systems to follow up discoveries immediately. This requires not only a structured data packet, to allow machines to make decisions, but also a fast notification for subscribers. In the past, email has been used with an automated receiver, but this protocol allows arbitrary delays at forwarding points and is no longer the best we can do. The RSS feed gives a web user the feeling of news alerts being pushed to their browser, but in fact this is a polling protocol initiated by the browser. Using RSS would pull us in opposite directions: a rapid polling so that subscribers get immediate events would saturate the machines of the publishers who are constantly answering the poll. A better protocol has a socket constantly connected so that a new message can be pushed to a client in milliseconds or less.

There are several such "push" technologies available. Instant Messaging is a huge industry, and much of it relies on the Jabber protocol, which is laid over the lower level XMPP (Extensible Messaging and Presence Protocol) protocol. Subscribers choose "Nodes" that are offered from a Jabber server (such as the one running at Caltech). From a node subscription can come a stream of related events: we might configure the streams above (SDSS-supernova, OGLE, GCN, etc) to each be a node.

Instant messaging software based on the Jabber protocol is available for implementing both clients and servers from `http://jabber.org`. VOEvent-specific software, including client applications, is available from `http://voeventnet.org` for several languages. Clients may additionally be written using an alternative transport method built directly on the TCP protocol using sockets, ports, and byte-counting for the messages.

Useful Links

eSTAR: eScience Telescopes for Astronomical Research
http://www.estar.org.uk [Accessed 13 July 2006].
GCN: The Gamma-Ray Burst Coordinates Network
http://gcn.gsfc.nasa.gov [Accessed 13 July 2006].
HTN: Heterogeneous Telescope Networks
http://www.telescope-networks.org [Accessed 13 July 2006].
IVOA VOEvent standard
http://www.ivoa.net/Documents/latest/VOEvent.html [Accessed 13 July 2006].
IVOA VOEvent Working Group
http://voevent.org [Accessed 13 July 2006].
LIGO: Laser Interferometer Gravitational Wave Observatory
http://www.ligo.caltech.edu [Accessed 13 July 2006].
LSST: Large Synoptic Survey Telescope
http://www.lsst.org [Accessed 13 July 2006].
Palomar-QUEST: A case study in designing sky surveys in the VO era
http://resolver.caltech.edu/CaltechCACR:2004.218 [Accessed 13 July 2006].
Pan-STARRS: the Panoramic Survey Telescope & Rapid Response System
http://pan-starrs.ifa.hawaii.edu/public/index.html [Accessed 13 July 2006].
RAPTOR: RAPid Telescopes for Optical Response
http://www.raptor.lanl.gov, and
http://www.thinkingtelescopes.lanl.gov (Thinking Telescopes Project) [Accessed 13 July 2006].
Robotic telescope infrastructure: RoboNet: RoboNet-1.0
http://www.astro.livjm.ac.uk/RoboNet [Accessed 13 July 2006].
RTML: Remote Telescope Markup Language
http://www.uni-sw.gwdg.de/~hessman/RTML, or
http://monet.uni-goettingen.de/twiki/bin/view/RTML (twiki) [Accessed 13 July 2006].
STC: Space-Time Coordinates Metadata for the Virtual Observatory
http://www.ivoa.net/Documents/latest/STC.html [Accessed 13 July 2006].
Swift: Catching Gamma-Ray Bursts on the Fly
http://swift.gsfc.nasa.gov/docs/swift/swiftsc.html [Accessed 13 July 2006].
VOEvent at NOAO
http://voevent.noao.edu [Accessed 13 July 2006].
VOEventNet: An implementation of a VOEvent network
http://voeventnet.caltech.edu [Accessed 13 July 2006].